THE DISCRIMINATION OF CUTANEOUS PATTERNS BELOW THE TWO-POINT LIMEN[1]

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I. INTRODUCTION

It has long been known that stimulation of the skin by a subliminal separation of compass-points is not by any means necessarily perceived as punctiform pressure. Kottenkampf and Ullrich,[2] for instance, speak of "the impression that the skin is being touched by an elongated body." Camerer[3] distinguishes four kinds of perception. Henri and Tawney,[4] Tawney,[5] and Judd[6] have found a variety of impressions

[1] From the Psychological Laboratory of Cornell University.

[2] R. Kottenkampf and H. Ullrich. Versuche ueber den Raumsinn der Haut der obern Extremität, *Zeit. f. Biol.*, VI, 1870, 42.

[3] W. Camerer. Versuche ueber den Raumsinn der Haut nach der Methode der richtigen und falschen Fälle, *Zeit. f. Biol.*, XIX, 1883, 282.

[4] V. Henri and G. Tawney. Ueber die Trugwahrnehmung zweier Punkte bei der Berührung eines Punktes der Haut, *Philos. Studien*, XI, 1895, 394 ff.

[5] G. Tawney. The Perception of Two Points not the Space-threshold, *Psych. Rev.*, II, 1895, 585 ff.

[6] C. H. Judd. Ueber Wahrnehmungen im Gebiete des Tastsinnes, *Philos. Studien*, XII, 1896, 409 ff.

ranging from one point to a line between boundaries. Leuba[7] noticed that "the passage from oneness to twoness is through a sensation of length." Bolton[8] mentions intermediate forms which lie between one and two points. Binet[9] obtained a special perceptive form within the limits of one and two points. Foucault[10] distinguishes no less than six intermediate perceptive forms. Gates,[11] working in the Cornell laboratory in 1915 by a strict psychophysical procedure, was able to assign quantitative values to such patterns as circle, line and dumb-bell, which lay between the extremes of one and two points.

The whole question of these cutaneous patterns was set in a new light when Titchener[12] in 1916 showed that, if no effort is made to rule out the stimulus-error, discrimination may be carried to a very high degree of delicacy. Titchener used his results to explain the discrepancy found by McDougall[13] in the cutaneous perceptivity of Englishmen and Torres Straits Islanders. An extension of this work by de Laski[14] seemed to show that further systematic investigation might make it possible to reconcile, in like manner, some of the outstanding controversies concerning the aesthesiometric experiment.

The present paper is a report of such an investigation. We have sought to determine the limits of discrimination of two-point impressions, when the subjects[15] are left entirely free to objectify them, to take them as cutaneous 'things' or 'objects,' in other words, to take up towards them the attitude of everyday life rather than that of descriptive psychology. We shall first state what our subjects have been able to do, and shall then try to show that shifts from the everyday to the psychological attitude will account for differences of

[7] J. H. Leuba. On the Validity of the Griesbach Method of Determining Fatigue, *Psych. Rev.*, VI, 1899, 576.

[8] T. L. Bolton. Ueber die Beziehungen zwischen Ermüdung, Raumsinn der Haut und Muskelleistung, *Psychol. Arbeiten*, IV, 1902, 192.

[9] A. Binet. La mesure de la sensibilité, *L'année psych.*, IX, 1903, 79 ff. Cf. J. F. Messenger, *Harvard Psych. Studies*, I, 1903, 130.

[10] M. Foucault. L'illusion paradoxale et le seuil de Weber, 1910, 124 ff.

[11] E. J. Gates. The Determinations of the Limens of Single and Dual Impression by the Method of Constant Stimuli, *Amer. Journ. Psych.*, XXVI, 1915, 152 ff.

[12] E. B. Titchener, in *Proc. Amer. Philos. Soc.*, LV, 1916, 569 ff.

[13] See *Reports of the Cambridge Anthropological Expedition to Torres Straits*, II, 1901, v. f., 1 ff.

[14] E. de Laski. On Perceptive Forms below the Level of the Two-point Limen, *Amer. Journ. Psych.*, XXVII, 1916, 569 ff.

[15] We use the term *subjects* rather than *observers*, since we made no demand for psychological observation and descriptive reports.

numerical results that have hitherto been ascribed vaguely to practice and fatigue.

II. Experimental

1. *Apparatus.* The apparatus consisted of a modification of the improved Jastrow aesthesiometer. We modified this instrument[16] by supporting it from the handle by means of a compression spring. This spring was placed about the stem of the aesthesiometer as an axis, between a stop at the upper end of the stem and the top of the handle, to which it was attached. The aesthesiometer can thus be lifted by the handle, with its weight compressing the spring. If the points are now brought into apposition with the skin and the handle is lowered from the stem, the weight of the instrument, as the spring extends, will gradually be transferred from the handle to the skin. The rate of depression of the handle, after the points have come upon the skin, determines the rate of application of the pressure; and the amount of depression, the amount of the pressure. (Since the instrument can be weighted and various springs used, any desired pressure can be obtained.) We found it convenient to encase the spring in an aluminum tube, which was attached to the handle and fitted over the stop at the upper end of the stem. This tube kept the spring in place, steadied the handle (since it fitted accurately over the stop), and would be more convenient to grasp, in manipulating the aesthesiometer, than the handle itself. In our case, however, a constant application of stimulus was obtained by means of the mechanical device described by Dimmick.[17] The amount of pressure employed was 15 grams $\pm$ .5 mg. (25 trials, measured on a chemical balance). The arm of the subject was placed in a plaster cast, and the apparatus was supported over the arm in such fashion that it could be moved in both directions in the horizontal plane. A silent pendulum was used for controlling the warning signals and the length of the stimulations.

2. *The Subjects.* The subjects were Mr. L. B. Hoisington (H), instructor in education, practised; Mr. F. L. Dimmick (D), assistant in psychology, highly practised in cutaneous observation; Miss J. M. Gleason (G), graduate fellow in psychology, well practised; Mr. P. T. Young (Y), graduate scholar in psychology; and Mr. G. J. Rich (R), graduate student in psychology. The last-named took part only in the preliminary work.

[16] The aesthesiometer will be described in detail later.

[17] F. L. Dimmick. On Cutaneous After-Images, *Amer. Journ. Psych.*, XXVII, 1916, 566.

3. *Determination of Pressure Intensity.* We have said that the pressure employed was that of 15 gr. This intensity of stimulus was chosen after we had made, in preliminary experiments, a comparison of the pattern-names obtained for the same stimuli at different intensities. The method of procedure was as follows.

The stimulus-differences 15 mm. and two-points-apposed were used. Each of these stimuli was given 9 times with a pressure of 10 gr. After every application the subject was asked to describe the pattern, and then to give a general characterization of the impression at the end of the ninth application. The same method was followed with pressures of 20 and 15 gr., respectively. Results showed that approximately the same patterns were obtained for the corresponding stimuli at the different pressure-intensities.

For instance, in 35 trials with 15 mm. separation, G reports dumb-bell (12) [18], two points (13), double paddle (10), with the intensity 10 gr.; dumb-bell (8), two points (12), and double paddle (15), with 20 gr.; dumb-bell (17), two points (13), double paddle (5), with 15 gr. D reports, for the same separation, two points (10), dumb-bell (12), long line (13), for pressure of 10 gr.; two points (15), dumb-bell (20), with 20 gr.; and two points (23), dumb-bell (12), with 15 gr. Similarly, R obtains line (22), dumb-bell (13), with pressure of 10 gr.; line (28), dumb-bell (7), with 20 gr.; and line (21), dumb-bell (14), with 15 gr. With two-points-apposed, in 35 trials, G reports line (12), short straight line (5), small dumb-bell (18), for 10 gr. pressure; line (22), short line (13), with 20 gr; line (25), short line (10), with 15 gr. D obtains one point, and R spot, in all 35 trials for every intensity of pressure, with two-points-apposed.

The middle pressure of 15 grams was selected as that to be employed throughout the investigation.

4. *Pressure Spots.* Another preliminary problem was that of determining whether it was necessary to avoid the stimulation of highly responsive pressure spots in applying the points. In other words, our aim was to find out whether the patterns obtained with the stimulation of highly responsive pressure spots differed from those which occurred when less responsive pressure spots or intermediate cutaneous areas were stimulated. The most responsive pressure spots within the area of stimulation were accordingly localized (in 15 trials), and marked by means of indelible ink. The stimulus employed for localization was a horse-hair of 0.105 mm. in diameter. This was fitted into an aesthesiometer tube, and adjusted to present a length of 38 mm., its stimulation value being 2.4 g/mm. (von Frey's tension units). The separations used in the work were 15 mm. and two-points-apposed.

First, 9 applications of the stimulus corresponding to the separation 15 mm. were given. Care was taken to stimulate a different intensive pressure spot every time. (Obviously, only one pressure spot could be stimulated in a given application, since the distance apart of the pressure spots did not necessarily correspond to the separation distance 15 mm.). The subjects were told to notice how the stimuli were alike, with a view to reporting a common pattern-name at the end of the ninth application. In a similar manner, 9 applications corresponding to the stimulus two-points-apposed were given, with the request for a report of a common pattern-name at the end of the ninth application. The above method of procedure was also used for the determination of pattern-names where the intensive pressure spots were

[18] Numbers in brackets indicate the number of times the pattern is reported.

avoided in the application of the points. The results showed that the stimulation of intensive pressure spots made no significant difference in the patterns obtained for the two separations.

In 50 trials (450 applications) with 15 mm. separation, G reports, with highly responsive pressure spots: double paddle (19), dumb-bell (31); without highly responsive pressure spots, double paddle (10), dumb-bell (26), two points (14). Similarly D reports: with highly responsive pressure spots, long line (41), two points (9); without highly responsive pressure spots, line (43), two points (7). In 30 trials, R reports: line (18), dumb-bell (12), with highly responsive pressure spots; and line (23), dumb-bell (7), without highly responsive pressure spots.

For two-points-apposed, with pressure spots, in 50 trials G reports: line (27), short, straight line (12), short dumb-bell (11); and line (28), short straight line (22), without responsive pressure spots. Similarly, D obtains one point for all 50 trials, both with and without the stimulation of highly responsive pressure spots. In 30 trials, R reports, with highly responsive pressure spots, spot (10), circle (20); and spot (30), with avoidance of such pressure spots.

We further tried to find out whether the stimulation of the highly responsive pressure spots as compared with the stimulation of the less responsive areas made a difference in the percentage of accuracy in the haphazard series. The method was much the same as that described above. The subject was given 9 practice applications of the separation 15 mm. and was asked to characterize the impression at the end of the ninth application, and also to memorize it with a view to identifying it later in a haphazard series. In a similar manner, he was given the stimulus of two-points-apposed. This was followed by a haphazard series of 10 applications, composed of 5 applications of each stimulus employed in the practice series. The subject was asked to judge which one he was receiving, as immediately as possible after it was applied. The procedure was followed, first, with the stimulation of the most responsive pressure spots, and secondly, with avoidance of these spots.

Although the investigation was not extensive, the results were definite enough to warrant the conclusion that the stimulation of the highly responsive pressure spots as compared with that of other areas made no significant difference in the percentage of accuracy obtained in the haphazard series.

In 4 haphazard series, with the stimulation of highly responsive pressure spots, G obtained an average of 80% accuracy, and on other areas also 80%, for stimulation with the separation 15 mm. For two-points-apposed, the same subject obtained 90% both with the stimulation of the highly responsive pressure spots and with that of other areas.

In 3 haphazard series, D obtained 100% with highly responsive pressure spots, and 93% with the less responsive areas, for the 15 mm. stimulation. For two-points-apposed D obtained 87% in both cases.

5. *Method: Haphazard Arrangement of Series.*

Eleven separations below the two-point limen were used:[19] app., 2, 5, 7, 10, 12, 15, 17, 20, 22, and 25 mm. They were

[19] The limens for D and G were accurately determined as 30 ± 0.8 and 32 ± 2.0 mm. respectively. Those for F and Y were less accurately determined as 29 and 33 mm.

arranged in pairs in all the mathematical combinations possible, and these pairs were drawn at haphazard during the course of the investigation, thus determining the order of the 55 experiments as follows:

1. app–15	15. 5–12	29. 5–15	43. 7–15
2. 10–20	16. 7–22	30. app–10	44. 15–17
3. 5–25	17. 17–22	31. 15–22	45. 12–20
4. 7–12	18. app– 2	32. 10–25	46. app– 5
5. app–17	19. 2– 7	33. 7–10	47. app–12
6. 10—17	20. app–22	34. 2–22	48. 5–22
7. 5–20	21. 7–17	35. 5–10	49. 17–20
8. 20–22	22. 2–17	36. 10–22	50. 2–15
9. 2–12	23. 12–25	37. 15–25	51. 2–25
10. 2– 5	24. 20–25	38. 5–17	52. 7–25
11. 15–20	25. 5– 7	39. 22–25	53. 17–25
12. 12–22	26. app–25	40. 12–17	54. 2–20
13. 7–20	27. 12–15	41. app–20	55. 2–10
14. app– 7	28. 10–12	42. 10–15	

Every experiment consisted of 10 haphazard series, each one made up of 10 applications, 5 of the stimulus corresponding to the first, and 5 of the stimulus corresponding to the second separation of the pair employed. There were, therefore, 100 applications in a single experiment. The order of application of the stimuli, within every series of 10, was determined separately for that series by the drawing of lots. The investigation as a whole, then, consisted of 100 observations upon every one of the 55 possible pairs of separations, or of 5500 observations for a single subject.

6. *The instructions.* Our first instruction was as follows:

"You will be given in a practice-series two cutaneous stimuli which I shall name 'A' and 'B' respectively. After four presentations of each, given in the order, A, B; B, A; A, B; B, A; with their names, I shall give you a series in which the stimuli A and B occur in haphazard order.

"You are to judge each impression as A or B, or you may report, 'I can't tell.' You may, however, use any other names which seem more appropriate or convenient to distinguish the two impressions.

"Make your judgment as quickly as possible. The stimulus will not be removed from your arm until you have made your judgment.

"Any observations or remarks that you care to make may be dictated to the experimenter at the end of the series."

This instruction, however, proved unsatisfactory. It became evident that if a stimulus A were paired in a given haphazard series with a certain B, A might always be recognized: whereas, if the same A were paired with a certain other B, it might never be recognized. This result seemed to indicate that

judgments were made in terms of A and not-A, or B and not-B, rather than in terms of A and B.[20]

Accordingly the instructions were changed to the following:

"In a practice-series I shall apply to your arm two cutaneous stimuli which I shall call 'A' and 'B.' I shall apply each stimulus twice, giving its name each time. You are to identify and to memorize the two impressions.

"I shall then give you a series in which the stimuli A and B occur in haphazard order. You are to judge the impressions as A or B, or you may say 'I can't tell.' You may, however, use any other name (*e. g.,* a descriptive term) that helps you to identify the impressions. Make your judgment as quickly as possible.

"Any observations or remarks that you care to make may be dictated to the experimenter at the end of the series."

The subjects still had difficulty in identifying the two impressions. In addition, they complained that the length of the practice-series was too short to permit them to memorize the patterns. The instruction was, therefore, altered to read as follows:

"You will be given nine[21] cutaneous stimuli that are just alike. Notice how these are alike all the way through with a view of reporting a common pattern-name at the end of the ninth. Be sure to look for likenesses. I shall ask for a report of pattern at the end of the ninth."

This instruction preceded the giving of the practice series. In the early part of the investigation the subject was instructed as follows before every haphazard series:

"You will now be given a haphazard series composed of the two stimuli which you have just received. I shall ask you to judge which one you are receiving each time. You may use any terms you like to designate the two stimuli."

As the subjects became practised, the instruction preceding the practice-series was shortened to "Nine of each," "Three of each," or was not given at all, while that employed with the haphazards became unnecessary and was consequently omitted.[22]

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[20] Our attention was called to this error by the fact that an impression which was apparently identified in one series might fail altogether of identification in another series. For instance, in the case of app-5, 5 mm. apparently was always recognized, whereas in the case of 5-10, this same 5 mm. was never recognized. Another indication was the fact that, in the haphazard series proper, there were as many different patterns for the 5 mm. stimulus as there were applications of that stimulus.

[21] This number was found convenient for covering the cutaneous area, since it permitted a uniform variation of the position of the points.

[22] The observation periods were one hour in length. At first, only 3 haphazards were given during the hour, but as the subjects became

The results which are the subject of discussion of this paper were obtained entirely under the final instruction.

7. *General Practice.* A certain amount of preliminary practice work was necessary in order to accustom the subjects to the conditions of the experiment. Among the initial difficulties we have already mentioned that of interpreting the instructions. During this period the judgments in the haphazards ranged from 50 to 80% in accuracy, whereas in the later series with maximal practice the judgments, as will be seen, ranged from 80 to 100%. G required 16 haphazard series, extending over a period of 5 hours, for practice. D required 10 haphazards, extending over a period of 3 hours; Y, 39 haphazards, covering a period of 13 hours; while H was able to make accurate judgments almost from the beginning.

8. *Experimental procedure.* The observation periods of one hour each occurred three times a week. The experiments were performed as often as possible in the early morning hours when the subject was free from fatigue.

The work was done on the volar distal right fore-arm in an approximately longitudinal direction. An area 40 mm. long by 10 mm. wide was marked off with ink in a place relatively free from veins and tendons. Topographical features of the skin ensured constancy in the marking of this area. The position of the points was varied as much as possible within the area in order to avoid fatigue of the skin.

We have said that a plaster cast was made for the arm of every subject. This kept the arm in the same position, and rendered it immovable throughout the course of the experiment. At first, the arm was taken out to rest during the interval between the practice and the haphazard series, as well as between the separate haphazard series. These rests were later omitted, however, as the subjects became practised.

The subject was comfortably seated at a table with his arm in the cast, which was excluded from his view by means of a cardboard screen. The experimenter gave the usual Ready-Now signals and applied the stimulus corresponding to the first member of the practice series. The stimulus was kept on the arm for a period of two seconds, the interval elapsing be-

practised, this number was gradually increased, until in particular instances it was possible to run off as many as 40 haphazards during the course of a single hour. In the early part of the work, 18 practice applications were given before every haphazard series of 10, *i. e.*, 9 of each stimulus of the pair. Later the practice series were lessened to 6, *i. e.*, 3 of each stimulus composing the pair. Finally, in the case where 40 haphazards were reached, it was necessary to give the practice series only once, namely, at the beginning of the experimental hour. This was possible only where the subjects obtained 100% accuracy, since the presence of an incorrect judgment in the haphazard series always necessitated the giving of a practice series before the next haphazard.

tween the separate stimulations being one and one-half seconds. This interval was later decreased to one second. At the end of the ninth application, the general pattern name was recorded. Similarly, a second practice series of nine was given. These were followed by a haphazard series. The length of application of the stimuli here was the same as that in the practice series.

The judgments in the haphazard series were usually made in terms of the pattern names given in the preliminary series. As a rule, they were made as immediately as possible after the application of the stimulus. Upon the completion of 10 haphazards, a new experiment was announced.

9. *Results.* Table I gives a summary of the results of the entire experiment. The numbers represent the percentages of correct judgments in the case of each member of a pair of stimuli. They are based on the averages of 10 haphazard series, *i. e.*, 100 judgments (50 on each stimulus), obtained at maximal practice.

The lower values in this table might very well have been raised to 100-100, with more results taken. The lower num-

TABLE I

Number of Experiment	Separations in mm.	D	G	Y	H
18	app- 2[23]	—— [24]	86- 92	——	——
46	app- 5	100–100	92- 92	94- 94	94- 86
14	app- 7	100–100	94- 90	96- 88	86- 86
30	app-10	100–100	96- 98	90- 92	98- 92
47	app-12	100–100	96- 94	86- 92	92- 86
1	app-15	100–100	100–100	94- 92	96- 94
5	app-17	96–100	98–100	94- 96	98- 96
41	app-20	100–100	100–100	86- 98	98- 94
20	app-22	100–100	100–100	84- 96	100- 92
26	app-25	100–100	100–100	86- 96	100- 92
10	2- 5	——	86- 94	——	——
19	2- 7	100–100	86- 90	88- 94	92- 96
55	2-10	100–100	100–100	92- 98	94- 90
9	2-12	100–100	92- 98	94- 94	94- 98
50	2-15	100–100	100–100	84- 88	98- 94
22	2-17	100–100	100–100	88- 92	88- 84
54	2-20	100–100	100–100	88- 96	98- 94
34	2-22	100–100	100–100	90- 92	98- 92
51	2-25	100–100	100–100	90- 98	100- 94

[23] Typical of the patterns reported are line, short line, dumbbell, double paddle, single paddle, oval, circle, oblong, rectangle and bar.

[24] The failure of an experiment is indicated by a dash.

TABLE I (Continued)

Number of Experiment	Separation in mm.	D	G	Y	H
25	5– 7	——	——	——	——
35	5–10	100–100	96– 94	98– 96	86– 86
15	5–12	100–100	100–100	96– 94	90– 86
29	5–15	100–100	94– 92	80– 94	90– 94
38	5–17	100–100	98– 94	94– 98	88– 94
7	5–20	98–100	100–100	86– 92	94– 88
48	5–22	100–100	100–100	84– 98	100– 88
3	5–25	100–100	100–100	98– 96	96– 90
33	7–10	96–100	92– 94	——	——
4	7–12	100–100	100–100	90– 98	88– 88
43	7–15	98–100	100– 96	84– 96	88– 94
21	7–17	100–100	96– 94	82– 92	96– 96
13	7–20	100–100	100–100	86– 88	96– 88
16	7–22	100–100	100–100	84– 94	98– 94
52	7–25	100–100	100–100	82– 94	98–100
28	10–12	——	——	——	——
42	10–15	100–100	96– 94	92– 94	90– 94
6	10–17	96– 94	92– 94	96– 98	86– 90
2	10–20	100–100	100–100	96– 88	98– 86
36	10–22	100–100	98– 96	98–100	94– 90
32	10–25	100–100	98–100	96– 98	92– 96
27	12–15	——	——	——	——
40	12–17	100–100	94– 90	92– 98	96– 96
45	12–20	100–100	100–100	88– 96	96– 96
12	12–22	100–100	98–100	90– 96	92– 94
23	12–25	100–100	100–100	94– 96	96– 84
44	15–17	——	——	——	——
11	15–20	100–100	94– 98	94– 92	98– 92
31	15–22	100–100	94– 98	98– 96	96– 92
37	15–25	100–100	98– 98	96– 96	88– 90
49	17–20	——	94– 98	——	——
17	17–22	100–100	94– 98	94– 98	94– 90
53	17–25	100–100	100–100	90– 98	92– 88
8	20–22	——	——	——	——
24	20–25	100–100	90– 92	94– 98	94– 96
39	22–25	——	94–100	94– 98	——

bers mean, in the majority of cases at any rate, some temporary disability.

10. *Discussion of results.* From a study of the table it is evident that the subjects either were able to distinguish be-

tween the separations with a considerable degree of accuracy, or were not able to make any distinction at all between the separations given them. The latter result is found, however, only in the case of separations which were very near together.

Table II gives the experiments which were declared by the subjects to be especially difficult. Where the experiment failed, that result is indicated by a dash. Difficulty is indicated by "X." Absence of mark means that the experiment was not difficult for that particular subject.

In the case of D and G, the distinction is clear-cut, while in the case of Y and H there is variation. If some subjective difficulty arises, it is, of course, possible for *any* pair to be regarded as difficult, no matter how wide the separation of the points.

In the case of the more difficult experiments we found that it was possible to take only two haphazard series at a time; after these, the subject was likely to break down completely.

TABLE II

TABLE OF DIFFICULTIES

Number of Experiment	Separations in mm.	D	G	Y	H
18	app- 2	—	X	—	—
46	app- 5	X	X	X	X
14	app- 7		X		
10	2- 5	—	X	—	—
55	2-10		X		X
25	5- 7	—	—	—	—
35	5-10	X	X	X	X
15	5-12			X	X
33	7-10	X	X	—	—
4	7-12	X		X	X
28	10-12	—	—	—	—
42	10-15			X	X
6	10-17	X	X	X	X
27	12-15	—	—	—	—
44	15-17	—	—	—	—
49	17-20	—	X	—	—
8	20-22	—	—	—	—
24	20-25	X	X	X	X
39	22-25	—	X	X	—

11. *Conditions which Derange the Experiment.* Throughout the course of the investigation certain factors were noticed which proved fatal to the securing of any results. When

these influences were operative, it became impossible for the subject, despite his best efforts, to identify the patterns presented to him in the haphazard series. This means that there was no series of graded judgments in the haphazard series, when these conditions occurred, since the percentage of accuracy dropped straightway from 100-80 to 20-0 and 40-0, leaving not even the possibility of a chance distribution of judgments. In other words, the haphazard series could not even be termed a 'bad' one, but was rather a complete failure. Furthermore, in the presence of these factors, the subjects were frequently unable to give a general characterization of the impression at the end of the ninth application of the practice series, so varied were the separate impressions. Under these conditions stimuli as widely separated as 25 mm. and 5 mm. were reported as giving the same pattern. Subjects also mention variations in the sensitivity of the area, and in the intensity, size, clearness and brightness of the impressions themselves.

A discussion of these factors and their influence upon the results follows.

Fatigue. D was particularly liable to fatigue. For instance,[25] at 5 p. m. 11/13/17, app-17, D's results were 40-20 (Av. 2), but at 10 a. m. 11/16/17, his results are 96-100 (Av. 6), for the same stimulus pair. Similarly at 5 p. m. 10/17/17, app-15, his results are 40-0 (Av. 2), but at 8 a. m. 10/20/17, they are 100-100 (Av. 5).

H was also affected by fatigue caused by staying up all night. At 10 a. m. 1/27/18, app-15, results are 20-0 (Av. 3), but on 1/30/18, at the same hour, they were 80-84 (Av. 5). In connection with the first series he remarks: "I can't feel the thing at all; the patterns are just the same—points." H also reports that, when he is fatigued, waves of numbness sweep over the arm from the finger tips to the elbow, preventing the obtaining of results, except for one or two series at the beginning of the hour.

Fatigue in G is also accompanied by numbness in the arm, which prevents the obtaining of patterns. For example, at 8 a. m. 1/4/18, 12-25, G obtains such results as 20-40 (Av. 3) in the haphazard series, but at 8 a. m. 1/8/18, she obtains 100-100 (Av. 5) for the same stimuli. G, however, was seldom troubled by fatigue.

Y experienced a general state of fatigue during a period of several days, which prevented the securing of any results, no matter what stimuli were employed. This period extended from 12/7/17 to 1/28/18, during which time Y was unable to give any results when the following stimuli were employed: 15-20, 12-22, 7-20, app-7, 5-12, 7-22, and app-25. Y remarks: "The period in which I did nothing was a period of general fatigue. I am just coming out of this state of

[25] A convenient formula will be used for the expression of the results given here: 1. Time of day; 2. Date; 3. Stimuli employed; 4. Results of haphazards in average percent; 5. Number of haphazards from which the average is obtained. (Ex: with stimuli app-15, 20-0 means 20% accuracy for apposed and 0% for 15.)

fatigue." [This was reported at 10 a. m. 2/1/18, when his results with app-22 are 80-100 (Av. 2)].

At 10 a. m. 2/2/18, in connection with the same experiment, Y obtains such results as 20-0 (Av. 2) and reports fatigue from being up late the night before. He remarks: "Yesterday the impressions were as clear as ice, now they tend to confusion. There is a change in the experiences themselves as they are given. There is a tendency for the points to turn and be at an angle to the axis of the arm. This is especially true of the smaller patterns. There is also a tendency for three points to come in. I have noticed that this usually means that I am no good at all. The impressions themselves are of low intensity and weak; the distance between the points varies, in the larger pattern. Sometimes the points are bright, other times they are dull, round, and more spread out. There is also a tendency for them to roll off my arm."

At 9 a. m. 2/27/18, with 2-17, results are 40-20 (Av. 4), and Y remarks: "The patterns become smaller and smaller when I fatigue out on them."

General Physical Condition. Both H and Y are unable to work when affected by cold or grippe. H at 10 a. m. 12/29/17, 10-17, obtains 20-0 (Av. 4). He remarks: "My arm is insensitive, there are waves of numbness." But on 1/8/17, at the same hour, he has no difficulty in getting 80-100 (Av. 3).

At 10 a. m. 1/9/18, H reports indigestion, and this throws off the results on 10-17 again, to 0-40 (Av. 3).

Y reports a cold, and consequently obtains no results in the following experiment. At 12 a. m. 11/23/17, app-17, he gives 20-20 (Av. 3), whereas results on 11/23/17, were 80-100 (Av. 3).

After-Images. A source of error inherent in the procedure itself was the arousal of cutaneous after-images. G was particularly subject to these images. They were especially troublesome where the separations were close together, and made it impossible to run more than one or two such haphazards in the course of an hour. Their occurrence also made it impossible to take more than three experiments in a single hour, as a rapid succession of stimulations was always accompanied by numerous after-images. When after-images appeared, the experimenter wiped the area gently with a soft cloth. This corrective was usually successful.

Towards the end of an experimental hour H frequently complains that all sorts of other impressions creep in, in nature like after-images. For instance, at 4 p. m. 2/14/18, 2-25, results are 0-20 (Av. 3) towards the end of the hour, but on the following day at the beginning of the hour the same stimuli give results 100-100 (Av. 5).

Emotional State. The emotional state of the subject frequently prevented the obtaining of any results.

D at 10 a. m. 11/20/17, app-17, 40-20 (Av. 4), says: "I hate the experiment—I am mad at the thing. I do not know what I am looking for. The thing is nerve-racking; you expect me to do well and yet you put everything in the way you can." But at the same hour on 11/21/17, with the same stimulus pair and no inhibiting emotional state, he obtains 100-100 (Av. 4). Again at 10 a. m. 12/13/17, 15-20, 40-0 (Av. 3), he says: "The emotional side makes a lot of difference. Every little thing you do bothers me—the making of the report, the putting down of the pencil, etc."

The giving of a difficult series at the beginning of the hour usually

annoyed D to such an extent, and upset him so much emotionally, that no results could be obtained during the remainder of the hour. For instance, the giving of 15-17, on 1/27/18 at 10 a. m., threw off the results in 12-20 to 40-0 (Av. 4).

Y frequently reports a variable mood, which is accompanied by variations in the experiences, as to distance apart, number, size and brightness. At 12 a. m. 12/5/17, 5-20, Y obtains 20-0 (Av. 3), when in a variable mood. Again, at 10 a. m. 1/30/18, 2-20, Y's results are 0-40 (Av. 4), and he reports: "I do not feel in the mood, I am nervous. I do not want to quiet down to this." But on the following day with the same experiment, at the same hour, his results are 100-100 (Av. 3), when he is in an even frame of mind.

Suggestion. The element of suggestion entered in with especial force when the memory of a difficult series carried over from one experimental hour to the next. At 10 a. m. 1/17/18, 22-25, in the case of D, gives no results. On the followwing day, D remarks that the first experiment is going to be difficult. Moreover, the slightest suggestion on the part of the experimenter was sufficient to influence the results. For example, at 8 a. m. 11/17/17, 10-17, G asks if the patterns which she is about to receive are difficult. The experimenter incautiously replied that the experiment might possibly be difficult, but that it had not yet been tried. This resulted in 0-40 (Av. 2). But on 11/19/17, at the same hour, the experiment gave 100-100 (Av. 3), with no difficulty at all.

Temperature of the Cast. It was necessary to keep the casts at a moderate temperature since extreme temperatures prevented the securing of results. For instance, G was unable to identify the patterns in the haphazard series when the cast was very warm. At 8 a. m. 12/27/17, 25-20, results were 33-33 (Av. 3), but under normal conditions on 12/28/17, results were 100-100 (Av. 2). Extreme cold had a similar effect. At 8 a. m. 1/7/18, 12-25, results were 20-0 (Av. 4), but are 100-100 (Av. 10), at the same time on the next day when the cast is at normal temperature.

At 2 p. m. 1/4/17, Y gets no pattern-differences for app-25, and consequently the haphazard is not given, but on the following day at 10 a. m. he obtains 86-96 (Av. 10), when the cast is at the usual temperature.

Noises. D was distracted by outside noises such as talking in an adjoining room, or the ringing of the chimes. At 5 p. m. 11/13/17, 7-12 the results are 40-40 (Av. 2), when D is disturbed by the ringing of the chimes, but are 100-100 (Av. 10) later, when the chimes have ceased to ring. Again, the results at 10 a. m. 10/23/17, for 10-20 are 60-50 (Av. 2) when there is conversation in the next room, but change to 80-100 (Av. 1) when the conversation has stopped.[26]

III. The Alleged Effect of Practice on the Two-point Limen

In the literature we find conflicting statements as to the influence of practice on the two-point limen. Some investigators

[26] Foucault (*op. cit.*, 180) finds that pain in the head and poor sleep render the perceptions uncertain. Noikow (see Note 41 below; 437 ff.) notices the disturbing effects of poor sleep, no breakfast, headache, cold, fever, being out late and being up all night.

assert that the limen can be greatly reduced by practice, and others hold that there is no such reduction.

The first experimental investigations in regard to the influence of practice on the limen were made by Volkmann and Fechner[27] in 1858. These investigators found a decided decrease in the limen with practice. For instance, the results of Volkmann show a reduction in the limen on the volar side of the left hand from 8 to 2 Paris lines (1 Paris line = 2.27 mm.), while the limen on the dorsal fore-arm decreased from 14.2 to 4.8. Similarly, the limen for Fechner's hand showed a decrease from 10.4 to 4.4, while that of the fore-arm changed from 14.9 to 7.5.

Dresslar,[28] in 1894, found that there is a decided increase in discriminative ability with practice. The value of the limen on the volar side of the left fore-arm, in a particular instance, decreased from 33 mm. to 2 mm. during the course of the morning, and from 26 mm. to 1 mm. in the afternoon.

Tawney[29] finds a decrease in the threshold value with practice in the case of some observers. In one case the threshold, on the left fore-arm, decreased from 50 mm. to 5mm. during the course of 20 days. Again, in the case of another observer, the threshold on the dorsal side of the right arm, above the elbow, showed a decrease from 55 mm. to 4 mm. But here there were frequently two thresholds present on the same day. For example, on a certain day the thresholds were 5 and 28, on the next day 7 and 30, then 8 and 30. Furthermore, when it was suggested to the observer that the influence of practice would be investigated, the value of the threshold decreased all the way from 14 mm. to 2 mm., while on the preceding day the values averaged 38 ± 4 (Av. 11).

In 1897, Solomons[30] found that the knowledge of the observer as to whether he was right or wrong had an influence upon the results. In the beginning of the experiment, both of his observers distinguished two points on the fore-arm at a distance of approximately one and one-half inches. However, after a few weeks' practice, the observer who had been informed as to the nature of his results distinguished two points at a distance of one-fourth inch, while the other observer still maintained the distance he had at the beginning of the experiment.

Foucault,[31] on the other hand, maintains that there is not any change in the threshold due to practice. His observer's threshold values are 12.75 mm., 11.25 mm., 12.18 mm., and 12 mm.

In order to explain the disagreement of these authors, we must take into consideration the fact that, with training, we attain a high degree of accuracy in the discrimination of 'objects' presented to us by the skin. Our own experiments

[27] A. W. Volkmann, Ueber den Einfluss der Uebung auf das Erkennen räumlicher Distanzen, *Ber. d. Sächs. Ges. d. Wiss.*, X, 1858, 38ff.

[28] F. B. Dresslar, Studies in the Psychology of Touch, *Amer. Journ. of Psychol.*, VI, 1894, 313 ff.

[29] G. A. Tawney, Ueber die Wahrnehmung zweier Punkte mittelst des Tastsinnes, mit Rücksicht auf die Frage der Uebung, *Philos. Stud.*, XIII, 1897, 163 ff.

[30] L. Solomons, Discrimination in Cutaneous Sensations, *Psych. Rev.*, IV, 1897, 246 ff.

[31] *Op. cit.*, 168 f.

show that, with training, distances as close together as 3 mm. can be discriminated without difficulty. This ability to distinguish between cutaneous objects may be used to account for the results of those authors who assert that there is a decrease in the limen with practice. For instance, the reduction of a limen from 40 mm. to 2 mm., in a particular case, may simply mean that the subject has changed his attitude in regard to the object which he was judging as the experiment progressed. In other words, the subject has been judging different objects, instead of the same object. He has, accordingly, reduced the size of the limen by changing his attitude in regard to the object judged. This reduction in the limen, due to a change of the object, has been wrongly called practice.

On the other hand, the results of those authors who affirm that there is no practice may be explained by the fact that the subjects have kept a constant attitude in regard to the object judged. Consequently, the limen has remained the same. Our own results indicate that there is no true practice-reduction except that which manifests itself in the initial stage. Practice, then, simply amounts to becoming acquainted with a particular object, so that we are able definitely to recognize it when it is presented; it means that we are getting the object, stably, at its lower limit. The 'reduction of the limen' depends upon other conditions.

IV. The Alleged Effect of Fatigue on the Two-point Limen

The results of previous investigators show a similar disagreement as regard the influence of fatigue upon the limen. There are those who declare that the aesthesiometer is a reliable measure of fatigue, as opposed to those who do not find such a condition.

Griesbach[32] was the first to observe that the limen is increased by fatigue. His subjects were pupils in the *Gymnasium* and in the *Oberrealschule*. Measurements were made at the end of every hour of school work during the course of the day. He finds an increase in the threshold on the forehead from 4 mm. to 11 mm., and on the red of the under lip from 7mm. to 19 mm. in the case of a 13-year-old pupil. Again, the threshold on the cheek increases from 11 mm. to 23 mm., and on the ball of the thumb from 6 mm. to 13.5 mm., in the case of a 16-year-old subject. Similarly, there is an increase in the threshold from 13 to 34 mm. on the cheek (front), during an examination day, for a pupil in the *Realschule*.

[32] H. Griesbach, Ueber Beziehungen zwischen geistiger Ermüdung und Empfindungsvermögen der Haut, *Arch. f. Hygiene*, XXIV, 1895, 124 ff.

Griesbach's[33] later measurements, made on members of the recruiting commission at Müllhausen, also show that fatigue causes an increase in the limen. In the case of the physician whose duty it was to examine the candidates the limen on the forehead measured 6.7 mm. at 8 o'clock in the morning, but after four hours' work increased to 15.5 mm. Similarly, the limen on the ball of the thumb (right) increased from 6.5 mm. to 8 mm.

The results of Wagner[34] and Vannod[35] agree with those of Griesbach. Wagner's results show an increase in the limen on the cheek-bone from 11 mm. to 24 mm., from 5 mm. to 12 mm. and again from 3 mm. to 14 mm.

Vannod observes an increase in the limen on the forehead from 3 mm. to 12 mm., and from 4 to 16 mm. on the cheek, for a 16-year-old pupil in the *Realschule*.

Blazek,[36] in his experiments on the pupils in the *Franz-Joseph-Gymnasium*, found that the curves in several cases showed an increase in the limen with fatigue. Schuyten[37] also finds that the aesthesiometric method is satisfactory for measuring the fatigue of school children. Binet[38] concludes that it is possible to measure the intellectual fatigue of the school child by means of the aesthesiometer.

Sakaki,[39] who experimented in the schools of Japan, found an increase in the value of the limen with fatigue. His curves, which are based upon averages, show an increase in the limen during the course of the school day.

Bonoff,[40] a school physician, worked upon the pupils of the *Gymnasium* and found that the aesthesiometer can be used to measure fatigue. He found an increase in the limen on the cheek from 5.2 mm. to 11.38 mm. (average results for pupils during the course of examinations which lasted seven days). The limen on the cheek of 21 candidates for the baccalaureate examination increased from 7.7 mm. at 7:30 a. m. to 12.7 mm. at 1 p. m.

Noikow's [41] results indicate that the aesthesiometer is an index for the measure of fatigue. His measurements were made on the fore-

[33] H. Griesbach, Weitere Untersuchungen ueber Beziehungen zwischen geistiger Ermüdung und Hautsensibilität, *Internat'l Mag. of School Hygiene*, I, 1905, 414.

[34] L. Wagner, Unterricht und Ermüdungsmessungen an Schülern des neuen Gymnasiums in Darmstadt, *Samml. v. Abhandl. aus d. Gebiete d. päd. Psychol. u. Physiol.*, I, 1898, Hft., IV, 1 ff.

[35] T. Vannod, La fatigue intellectuelle et son influence sur la sensibilité cutanée, *Dissert. med. de Bern*, 1896, 1 ff.

[36] B. Blazek, Ermüdungsmessungen mit dem Federaesthesiometer an Schülern des Franz-Joseph-Gymnasiums in Lemberg, *Zeit. f. päd. Psychol, u. exp. Päd.*, I, 1899, 311 ff.

[37] M. C. Schuyten, Comment doit-on mesurer la fatigue des écoliers, *Archiv. de Psychol.*, IV, 1904, 113 ff.

[38] A. Binet, Recherches sur la fatigue intellectuelle scolaire et la mesure qui peut en être faite au moyen de l'esthésiomètre, *L'Année psychologique*, XI, 1905, 1 ff.

[39] Y. Sakaki, Ermüdungsmessungen in vier japanischen Schulen, *Internat'l Mag. of School Hygiene*, I, 1905, 86 f.

[40] N. Bonoff, Étude médico-pédagogique sur l'esthésiometrie et la simulation à l'école, *International Mag. of School Hygiene*, IV, 1907-8, 387 f.

[41] P. M. Noikow, Aesthesiometrische Ermüdungsmessungen, *Internat'l Mag. of School Hygiene*, IV, 1907-8, 437 ff.

head before and after fifteen minutes' work in arithmetic. In the case of one subject, the threshold increased from 5.3 mm. to 11.8 mm. For another subject, there was an increase from .2 mm. to 10.5 mm. Again, in the case of a girl in the elementary school, he finds an increase in the threshold from 1.9 mm. to 7 mm. after a lesson in reading. However, he finds that there is a lessening in the value of the threshold after very strenuous work. For example, in the case of one subject, the threshold on the forehead decreased from 8.5 mm. to 1mm. after a written examination, while that of another decreased from 12.4 mm. to 2.5 mm. after a two hours' examination. He attributes this decrease in the threshold-value to hyperaesthesia.

Offner[42] states that the relationship between fatigue and the spatial limen is sufficient to justify the use of the aesthesiometer as a measure of fatigue, more correctly as a measure for one of the symptoms of fatigue.

Foucault,[43] in his experiments upon two children, noticed that an excessive prolongation of the experiment resulted in an appreciable increase in the threshold. The first case is that of an eight-year-old girl, upon whom he made 12 successive determinations on the second phalanx of the dorsal side of the index-finger, with short intervals for resting. The threshold-values were as follows: 8 mm., an irregular series, then 8, 10, 8, 10, 8, 10, 12, 12, 12, 12. On the evening of the same day he obtained: 8, 12, 14, 14. The second case is that of a blind child, eleven years of age. The results were as follows: 12, 10, 10, 12, then 16, then an irregular series. He concludes that it is not surprising that the Griesbach method succeeds, in the light of the above results, provided, of course, that one is not too exacting on the quality of the measurement.

On the other hand, the validity of the Griesbach method for the determination of fatigue has been severely criticised and questioned. Leuba,[44] who experimented upon adults and college students, concludes that the aesthesiometric method is not to be regarded as a definite measure of fatigue, since many other factors must be taken into consideration, which are not capable of being measured. Germann,[45] whose results are based upon the tests of a single subject, was unable to find any relation between fatigue and the limen. Ritter,[46] in his experiments upon the students in the *Gymnasium,* did not find that the aesthesiometer could be used to measure fatigue. Bolton[47] concludes that the size of the threshold is not a measure of the effects of fatigue or mental work. His tables show that severe mental work, lasting for two hours, did not affect the threshold sufficiently to be detected by the aesthesiometer. Kraepelin[48] states that within very wide limits a

[42] M. Offner, Mental Fatigue, Eng. trans. Baltimore, 1911, 36 f.

[43] Op. cit., 181 ff.

[44] J. H. Leuba, On the Validity of the Griesbach Method of Determining Fatigue, *Psych. Rev.* VI, 1899, 573 ff.

[45] G. B. Germann, On the Invalidity of the Aesthesiometric Method as a Measure of Mental Fatigue, *Psych. Rev.,* VI, 599 ff.

[46] C. Ritter, Ermüdungsmessungen, *Zeits. f. Psychol.,* XXIV, 1900, 401 ff.

[47] T. L. Bolton, Ueber die Beziehungen zwischen Ermüdung, Raumsinn der Haut und Muskelleistung, *Psychol. Arbeiten,* IV, 1902, 175 ff.

[48] E. Kraepelin, Ueber Ermüdungsmessungen, *Arch. f. d. ges. Psychol.,* I, 1903, 9 ff.

definite relationship between size of threshold and degree of fatigue cannot be established.

Meumann[49] admits that the threshold is heightened by fatigue, but states that the increase is only very indirect and is complicated by many other factors, about which little is known. Whether the threshold increases in proportion to fatigue and permits of the use of the value which is found, as a real measure of fatigue, is a question which we cannot answer.

Martyn[50] concludes that changes in the spatial threshold are not sufficiently constant to be regarded as sure signs of fatigue in its early stages. Her results, however, do show just the kind of increase in the threshold which we should expect. For instance, the average of 10 thresholds taken before one hour's adding every day for 10 days was 7.65 mm., as compared with the threshold of 9 mm. which was taken after the adding, in the case of one subject. Again, the threshold for a second subject was 6.09 mm. before adding, but 6.87 mm. after adding, while that of a third subject increased from 7.30 mm. to 7.83 mm. These increases in the limen, according to our notion, were probably due to fatigue. The measurements cited above were made upon the left zygomatic arch.

It is clear from our own experiments that the initial determination of the two-point limen may mean very different things. If the experimenter happened to start with the two points clearly differentiated, fatigue will have a relatively small effect; but if the point of departure is some cutaneous pattern subliminal to two points, which nevertheless in a fresh condition can be distinguished from the pressure of a single point, then fatigue will, as our experiments show, make the identification of this pattern impossible and thus tend to raise the recorded limen.

It is evident, then, that if the limen which is initially determined is not the real two-point limen, it is impossible to keep a constant attitude when fatigue is present. For instance, the increase in the limen from 13 to 34 mm. on the cheek (Griesbach) may simply mean that the subject had for his initial limen some subliminal cutaneous pattern which, in a fresh condition, could be distinguished from the pressure of one point. With fatigue, the identification of this pattern became impossible. Consequently the subject was judging different 'objects' at the two stages of the test.

On the other hand, the results of those authors who assert that the limen does not increase with fatigue may be explained by the fact that the limen which was first determined was the real two-point limen, and not some subliminal cutaneous pattern which would be distinguished from the pressure of

[49] E. Meumann, Vorlesungen zur Einführung in die experimentelle Pädagogik und ihre psychologischen Grundlagen, II, 1907, 90 ff.

[50] G. W. Martyn, A Study of Mental Fatigue, *British Journ. of Psychol.*, V, 1913, 427 ff.

one point when the subject was in a fresh condition. Consequently, the limen remained approximately the same when the subject became fatigued. Our own results indicate that a constant attitude is possible only in cases where a real two-point limen has been determined in the beginning of the experiment.

Conclusions

(1) Our results show an extreme delicacy of discrimination below the level of the two-point limen. It is possible, for instance, to distinguish distances as near together as app-2, and 2-5.

(2) The subjects either were able accurately to distinguish between the cutaneous patterns or failed completely.

(3) The subjects were frequently unable to distinguish between the separations presented to them because of the fact that certain conditions such as physical disability, suggestion, temperature of the cast, etc., were operative. When these conditions were present it was impossible for the subjects to distinguish between the very widest separations.

(4) Very considerable changes in the limen, which have been ascribed to fatigue, are probably due to the fact that the object of judgment was not kept constant throughout the course of the investigation. The limen initially determined was in all probability not the limen of clear separation, but only some subliminal cutaneous pattern.

(5) We have been able to account for the divergent views held heretofore as to the effect of practice on the two-point limen. We have shown that the practice-effect of certain investigators is really not due to practice at all, but rather to a shift of attitude on the part of the subjects, involving their occupation at different periods of the investigation with different cutaneous objects.